Fast Track Insights

What you need to know about Quantum & it's possibilities to stay ahead

TNO innovation for life

TODAY'S PROGRAMME

1. Basic principles of Quantum Technology
2. State of Tech: Quantum Sensing
3. How to join the revolution of Quantum – invest, collaborate & accelerate

Basic principles of Quantum Technology

Henk Polinder | Senior Scientist

The revolution of Quantum – what are the main ingredients & how did it start?

1. **Quantum mechanics:**
   Understanding the physical laws that apply to vary small objects (superposition and entanglement, etc.)

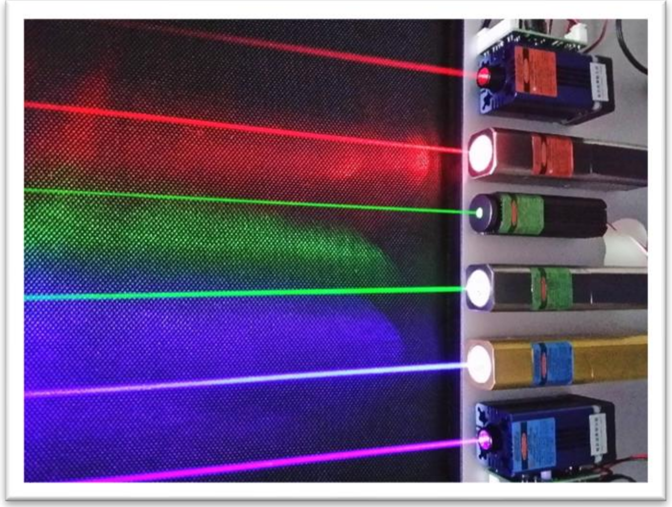
2. **Quantum devices:**
   devices designed to exhibit some of the Quantum mechanical properties

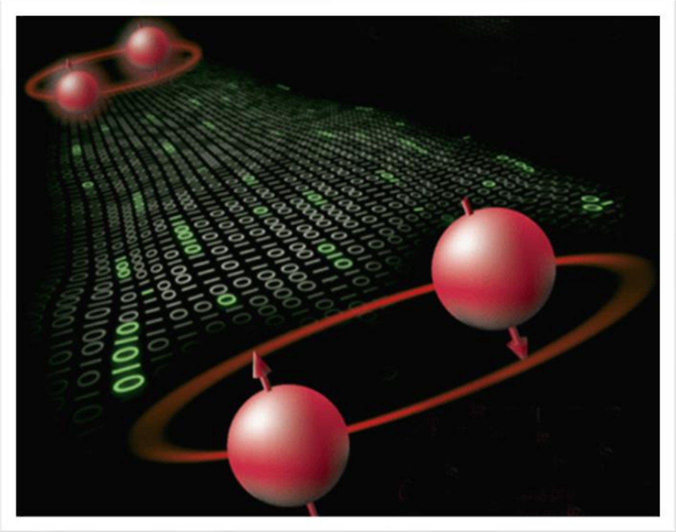
3. **Quantum systems:**
   devices assembled into complete functional systems, leading towards more powerful applications

How the Quantum revolution evolves

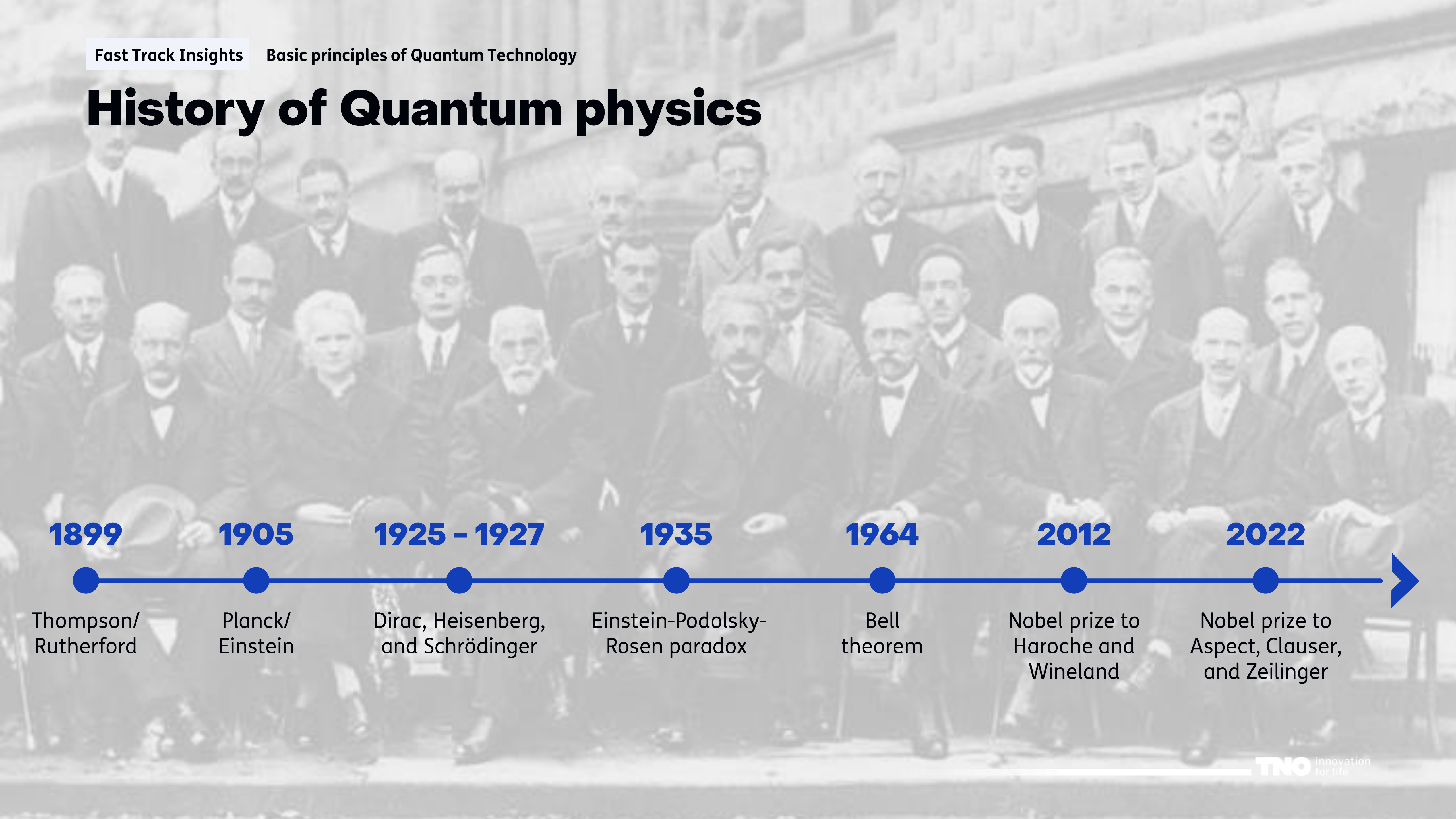
- 1st revolution: Understanding and applying Quantum-mechanics. Leading to inventions of transistors, lasers.

- 2nd revolution: Using Quantum-mechanical properties as superposition, entanglement, and controlling individual Quantum systems. Leading to more powerful applications, like Quantum computing, communication, and sensing.





History of Quantum physics

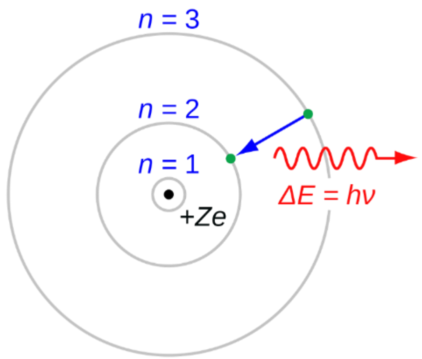


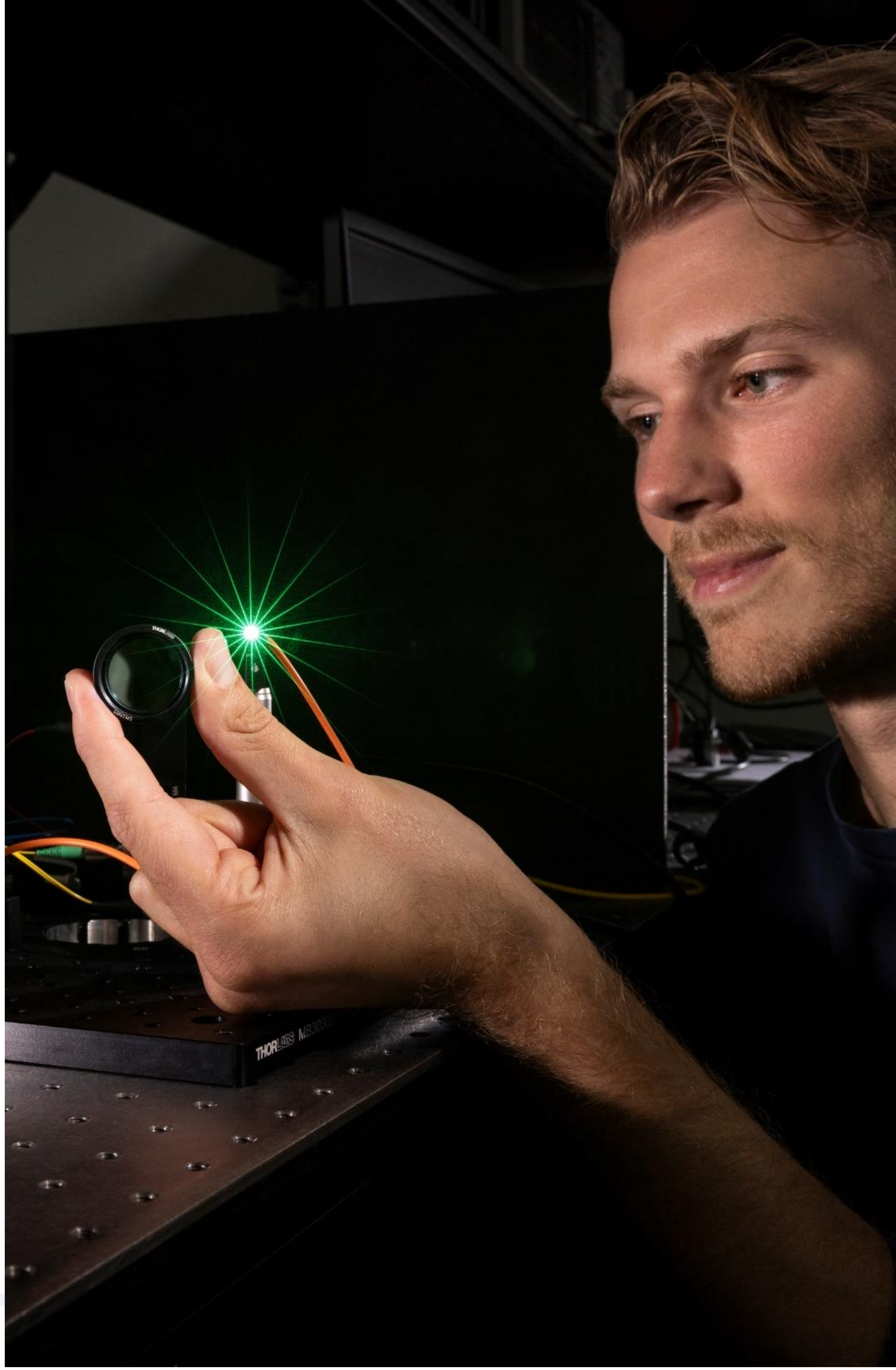
- **1899** — Thompson/ Rutherford
- **1905** — Planck/ Einstein
- **1925 - 1927** — Dirac, Heisenberg, and Schrödinger
- **1935** — Einstein-Podolsky-Rosen paradox
- **1964** — Bell theorem
- **2012** — Nobel prize to Haroche and Wineland
- **2022** — Nobel prize to Aspect, Clauser, and Zeilinger

Quantum mechanical principles

- **Quantization** of physical quantities like e.g. energy or momentum (i.e. restricted to discrete values)

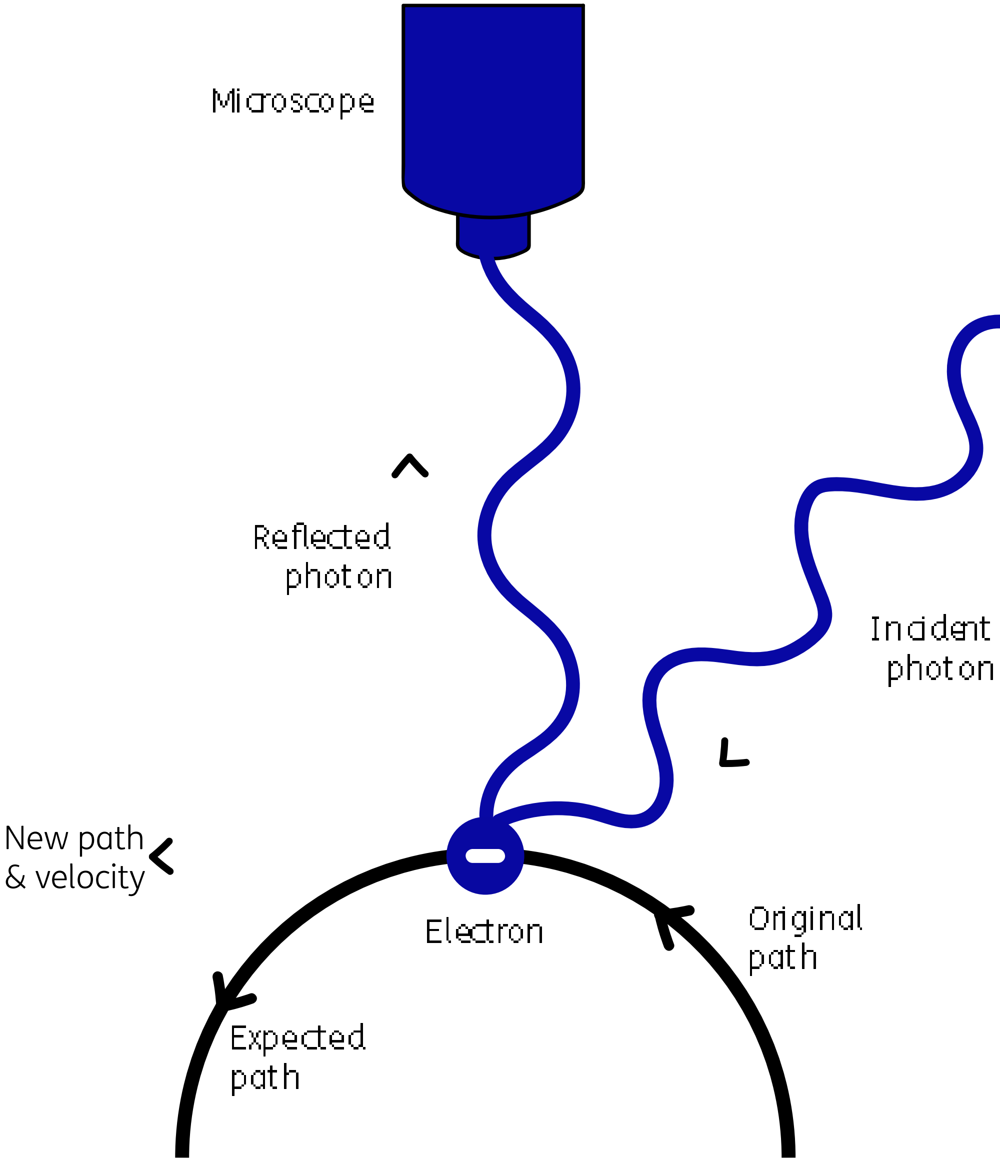
$$E_n = \frac{n^2 \pi^2 \hbar^2}{2mL^2}$$





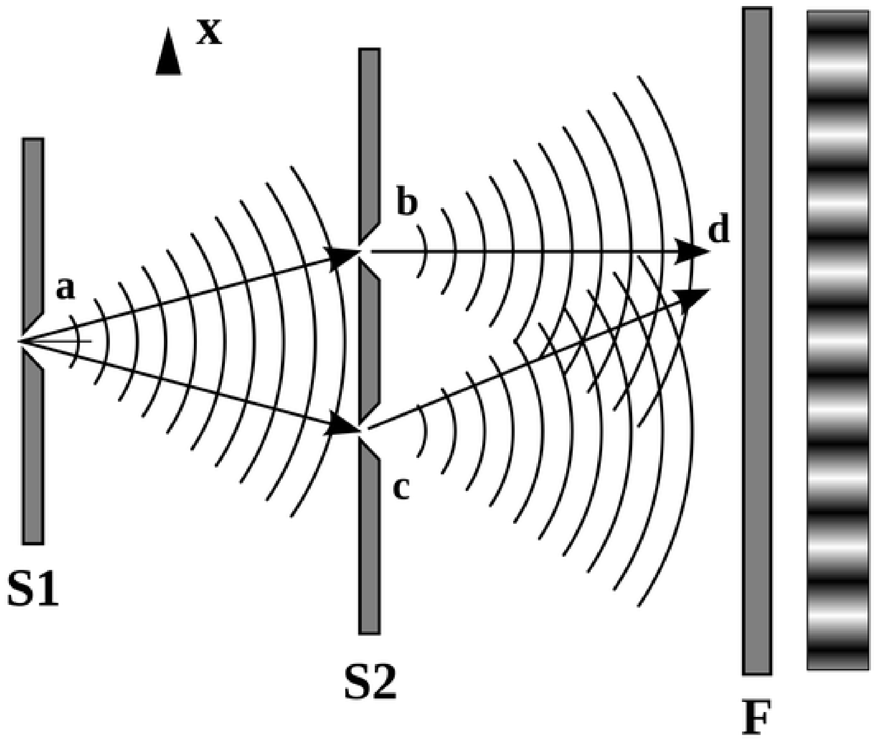
Quantum mechanical principles

- Heisenberg's **uncertainty** principle → **fundamental limit to the accuracy** with which values for certain pairs of physical quantities of a particle, such as position and momentum can be measured $(\Delta X)(\Delta P) \geq \hbar/2$.



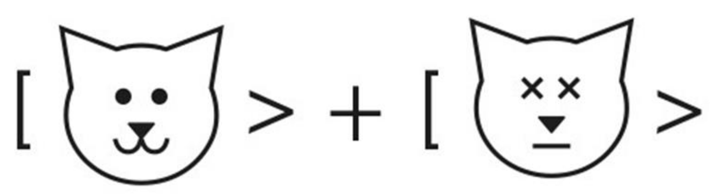
Quantum mechanical principles

- **Wave–particle duality** → both of the classical concepts "particle" or "wave" are needed to fully describe the behavior of Quantum states.



Quantum mechanical principles

- **Quantum superposition** of wave functions – wave function $|\psi(x,t)\rangle$ related to probabilities of observing a particle at position x at time t.

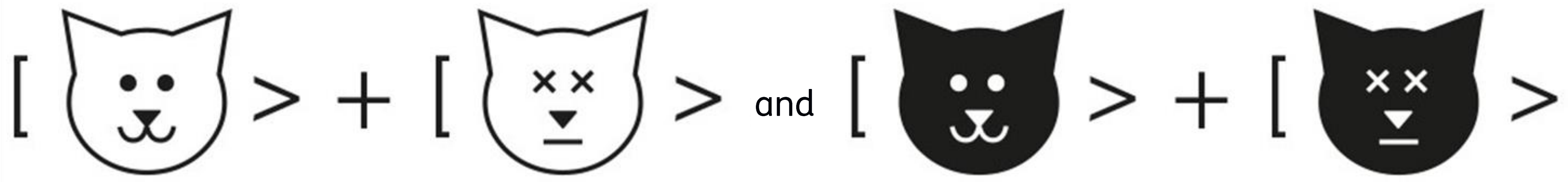


- **Quantum measurement** → Problem: collapse of superposition state.

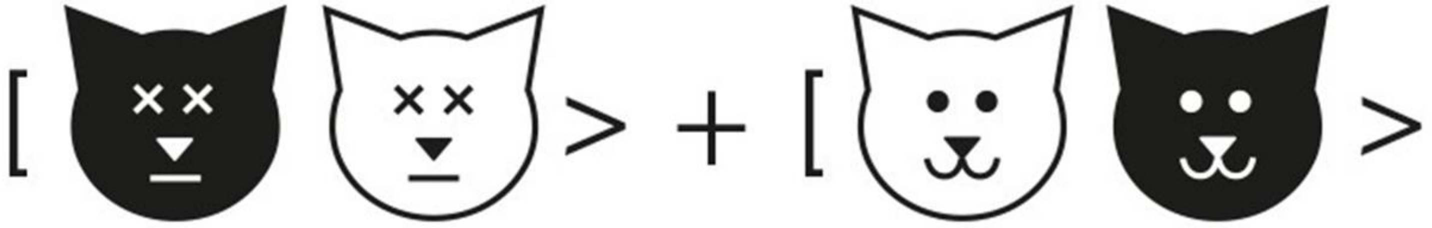
Quantum mechanical principles

- **Quantum entanglement →** particles are generated or interact in a way such that the Quantum state of each particle cannot be described independently of the state of the other particles (a strong type of correlation that does not have a classical counterpart).

- Not entangled

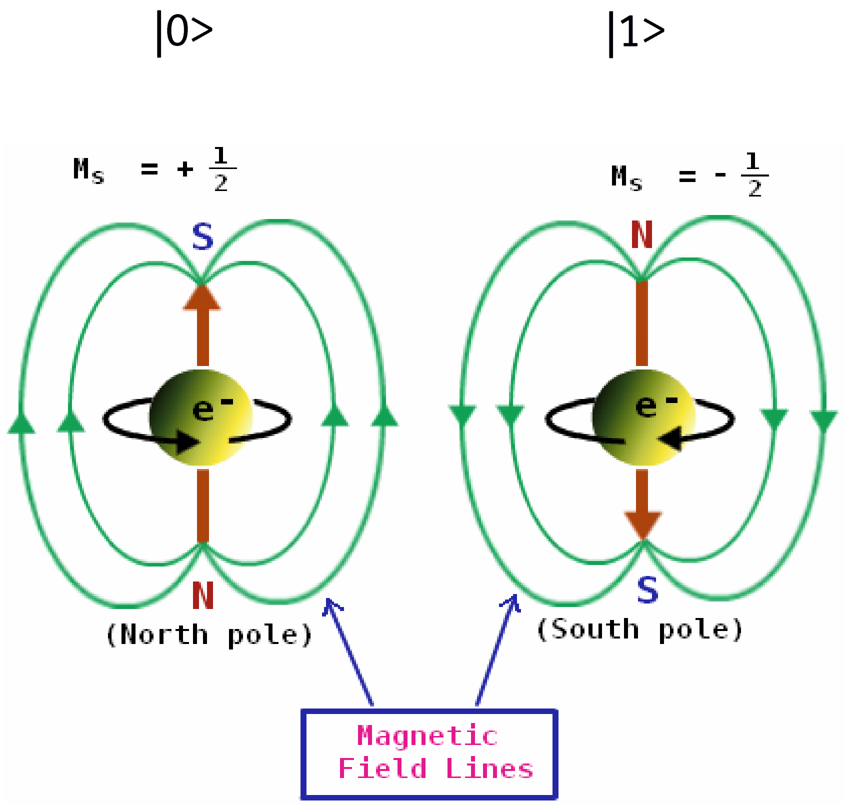


- Entangled



Quantum Bit

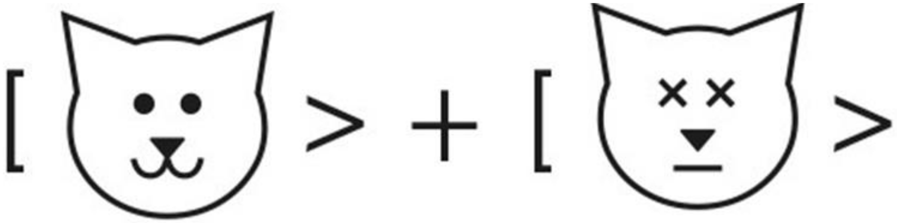
- Two discrete quantized levels + superposition - **Quantum bit (qubit)**
- Physical qubit examples:
  - ‘isolated’ spin ½ particle e.g. an electron
  - Superconducting
  - NV centres in diamond



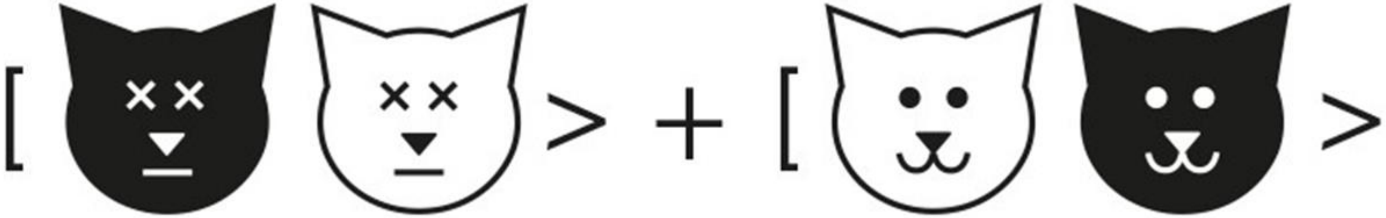
Quantum resources

- Which Quantum principles are powerful **resources** that may lead to technology having **Quantum advantage**?

- **Quantum superposition**

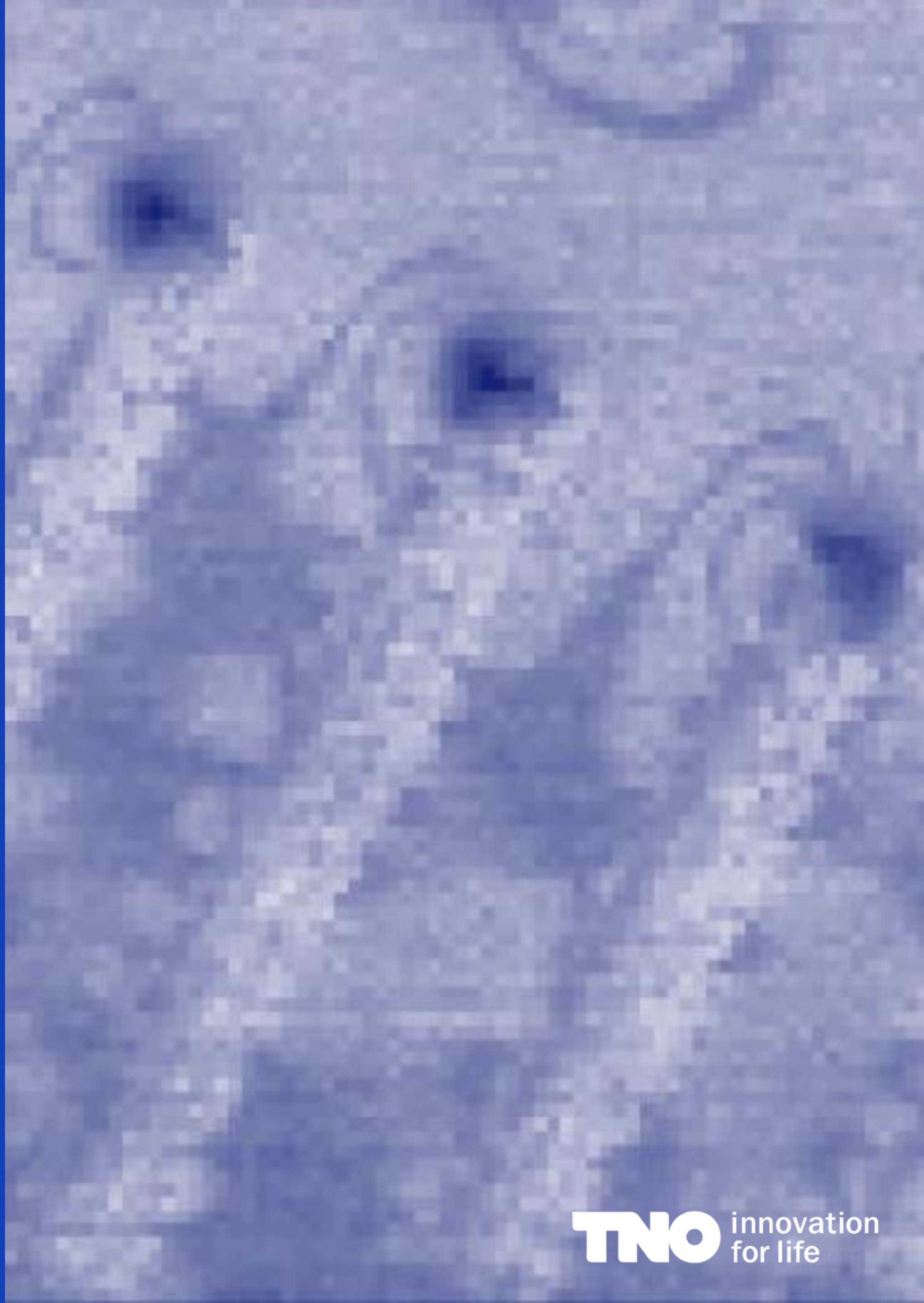


- **Quantum entanglement**



State of tech: Quantum Sensing

Clara I. Osorio Tamayo | Senior Scientist



Areas of Quantum Applications

1. Quantum Communication
2. Quantum Computing
3. **Quantum Sensing**

Military & security applications

Of quantum technology

Algorithms – computing applications

Quantum cryptography – pqc – migration

Quantum (inter)networks and communication

Ecosystem development and strategy consulting

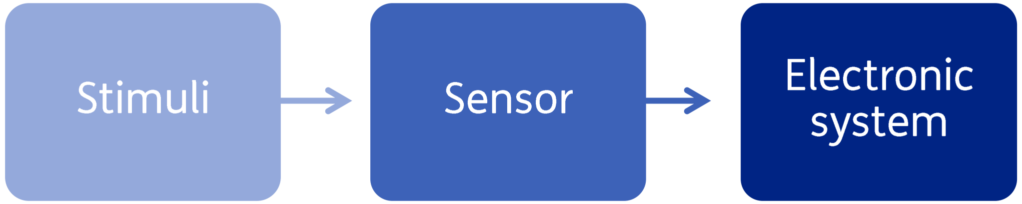
Quantum computing engineering

Quantum communication (in space)

Quantum sensing

Intro to Quantum Sensing

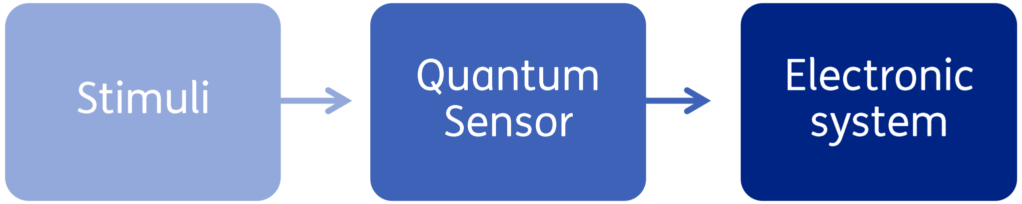
What is a Sensor?



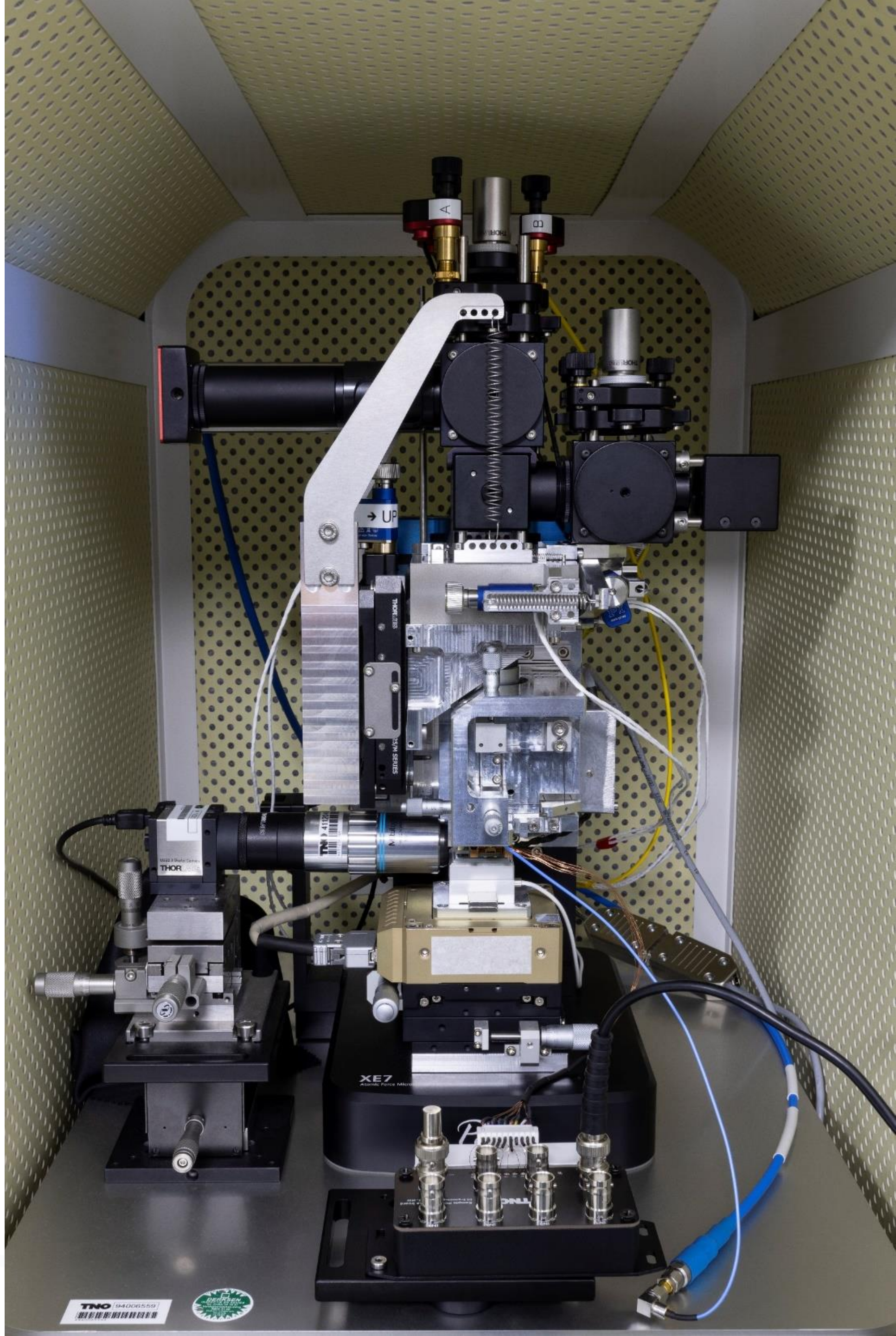
- A sensor is a device that receives a stimulus and responds with an electrical signal
  - Electric: Current, voltage, charge, etc.
  - Signal: Amplitude, phase, frequency, etc.
- Sensing is a particular case of information transfer, which always requires energy transfer

Image: SeeedStudio Grove Creator Kit – Beta (30 in 1 Sensor Kit)

What is a Quantum Sensor?



- The process of translating stimuli to electric signals is mediated by
  - A quantum system (a system with few energy levels)
  - The use of coherence
  - The use of entanglement



Types of Quantum Sensors

	Gas				Solid-state								
Systems	Neutral atoms		Other atomic states		Solid-state spins				Superconducting circuits			Other sensors	
	Atomic vapor	Cold cloud	Trapped ions	Rydberg atoms	NMR Sensor	Donors in Si	Quantum dots	NV centers	SQUID	Flux qubit	Charge qubit	Optome-chanics	Interfero-meters

Examples of Quantum Sensors

TNO innovation for life

Example 1: Atomic Gravimeter

	Gas				Solid-state									
Systems	Neutral atoms		Other atomic states		Solid-state spins				Superconducting circuits			Other sensors	
Physical quantities	Atomic vapor	Cold cloud	Trapped ions	Rydberg atoms	NMR Sensor	Donors in Si	Quantum dots	NV centers	SQUID	Flux qubit	Charge qubit	Optome-chanics	Interfero-meters
Magnetic field													
Electric field													
Acceleration													
Rotation													
Displacement													
Time/Freq.													
Force													
Mass													
Pressure													
Temperature													

> TRL 4 technology validated in lab

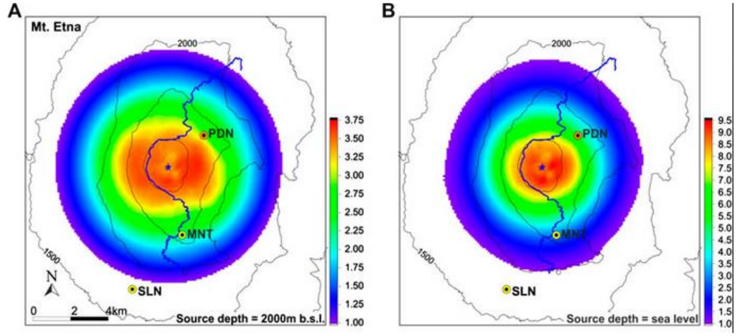
> TRL 7 system prototype demonstration in operational environment

Example 1: Atomic Gravimeter

Long term measurements of gravity fields

Features:

- Absolute measurements
- Similar accuracy and stability that classical gravimeters
- Portable and low power consumption
- Continuous operation (years)
- Lower price (~100 k€)



Sources: https://www.muquans.com/product/absolute-quantum-gravimeter/
The NEWTON-g Gravity Imager: Toward New Paradigms for Terrain Gravimetry. Front. Earth Sci., 09 October 2020 Sec. Solid Earth Geophysics. Volume 8 - 2020 |

Example 2: Optically Pumped Magnetometers

	Gas				Solid-state								
Systems	Neutral atoms		Other atomic states		Solid-state spins				Superconducting circuits			Other sensors	
Physical quantities	Atomic vapor	Cold cloud	Trapped ions	Rydberg atoms	NMR Sensor	Donors in Si	Quantum dots	NV centers	SQUID	Flux qubit	Charge qubit	Optome-chanics	Interfero-meters
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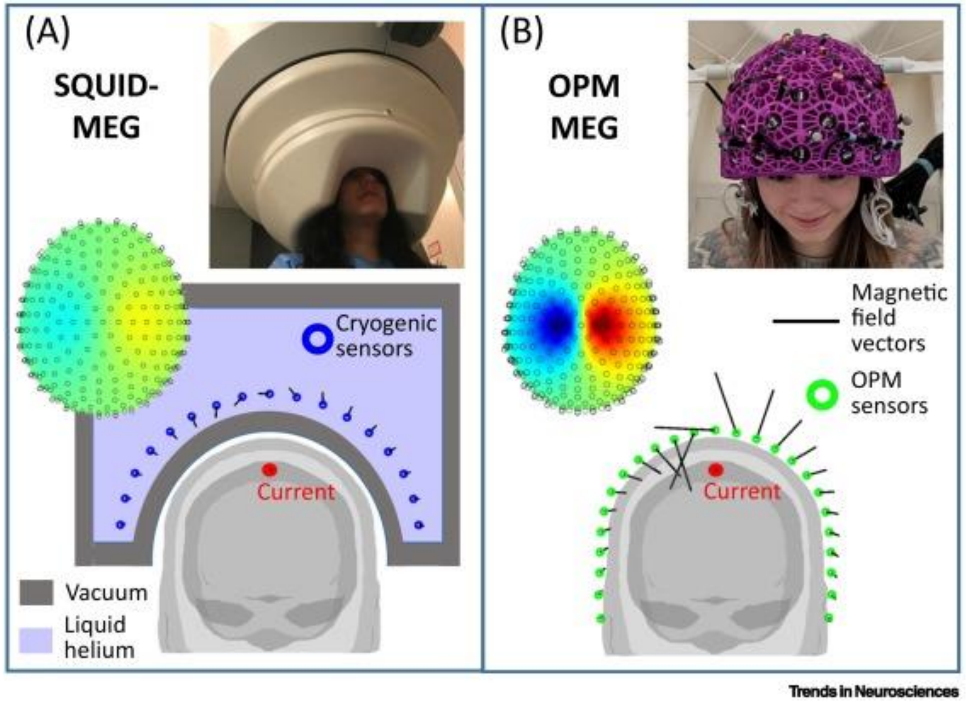
Example 2: Optically Pumped Magnetometers

High resolution magneto encephalogram

Features:

- High sensitivity (<15 fT/√Hz)
- Lower power consumption (0.7 W sensor head)
- Room temperature operation
- Better spatial resolution
- Smaller size



Images: Map of global MEG systems. – Wikipedia | Trends in Neurosciences. Volume 45, ISSUE 8, P621-634, August 2022

Example 3: NV Scanning probe microscopes

	Gas				Solid-state								
Systems	Neutral atoms		Other atomic states		Solid-state spins				Superconducting circuits			Other sensors	
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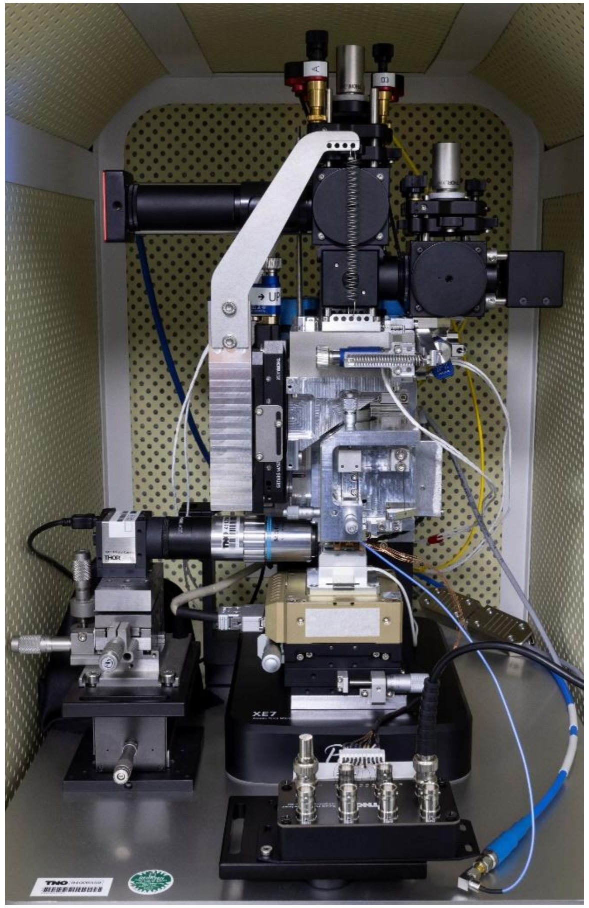
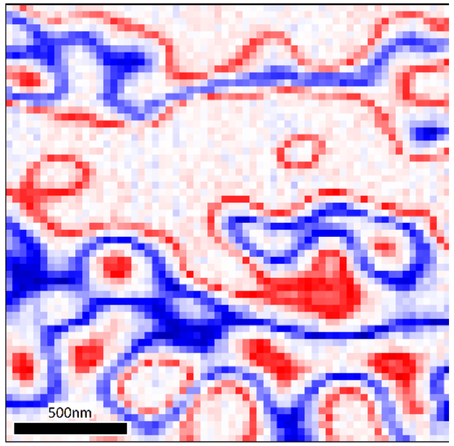
Example 3: NV Scanning probe microscopes

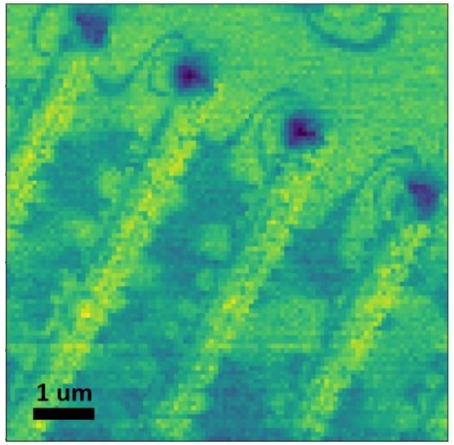
Non-destructive high-resolution measurement of magnetic fields, currents and temperatures.

Features

- Resolution $\sim 50\ \mathrm{nm}$
- Sensitivity $\sim 5\,\frac{\mu\mathrm{T}}{\sqrt{\mathrm{Hz}}}$
- Target speed: 100 pixels per second







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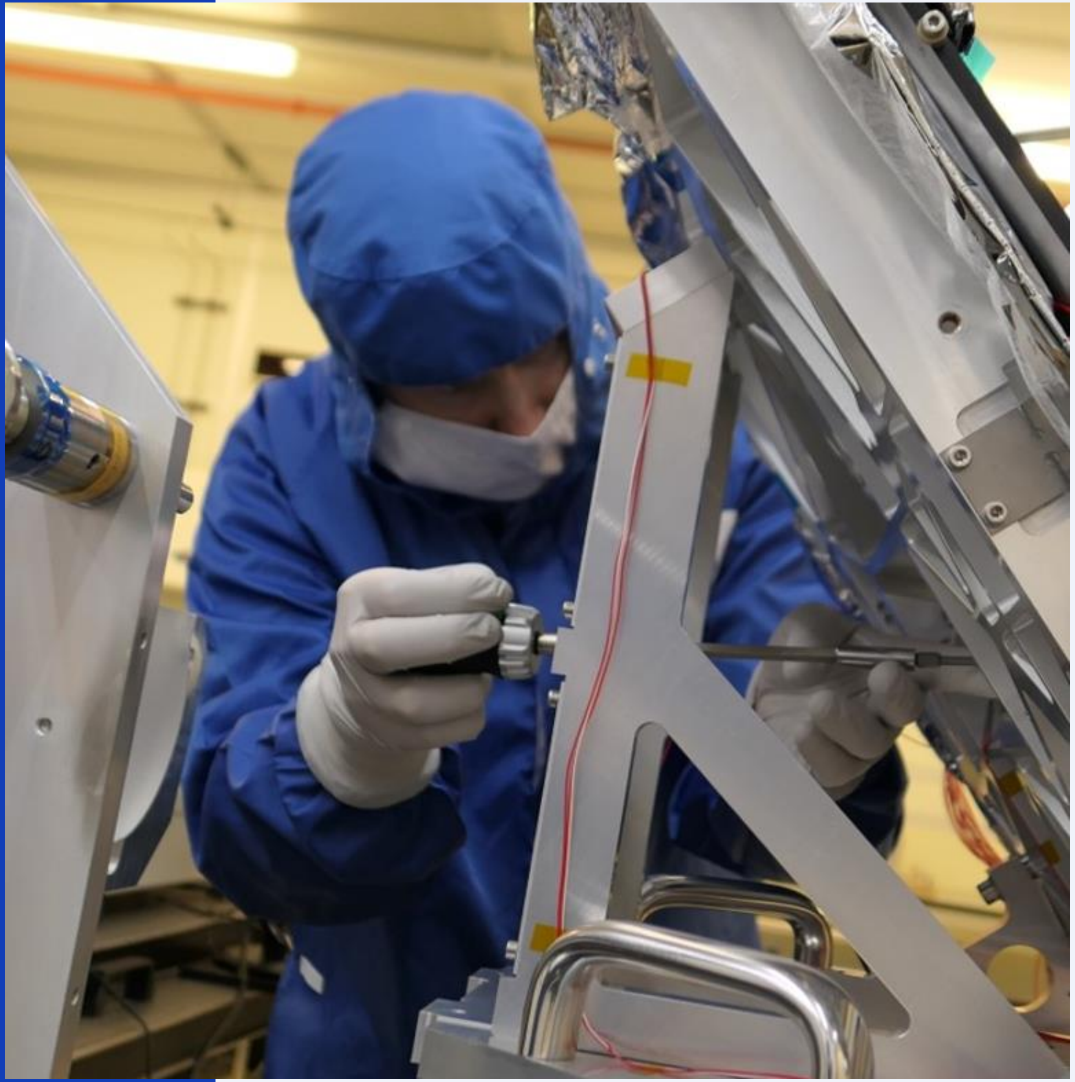
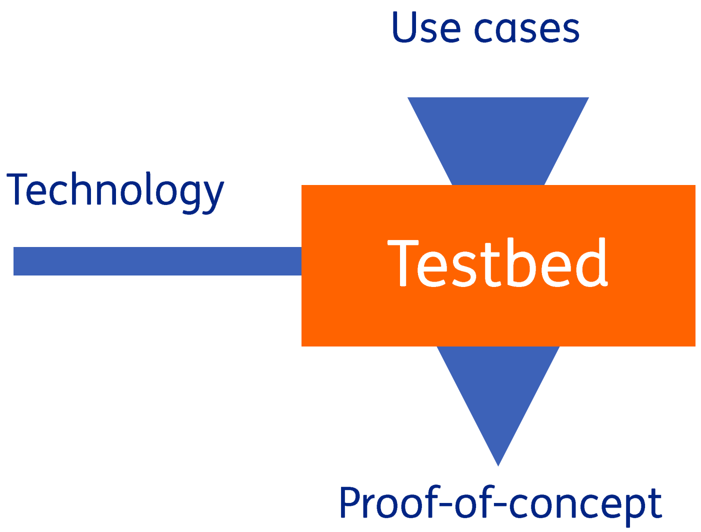
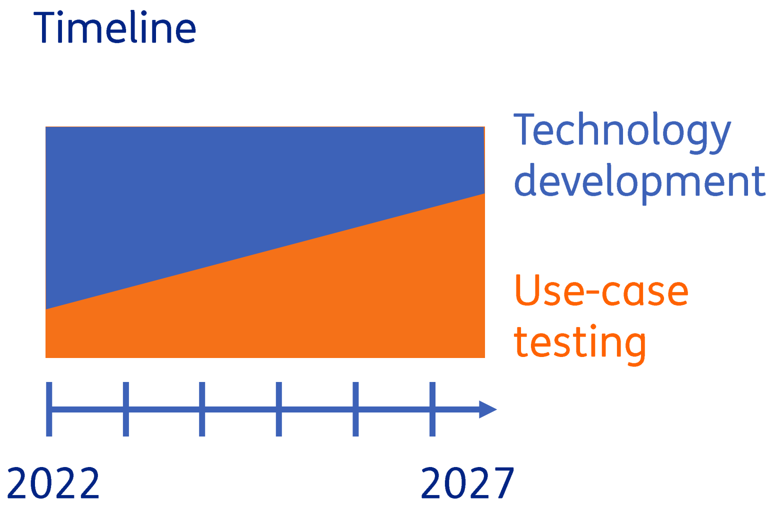
Quantum Sensing at TNO

We use TNO's technology and know-how to accelerate the industrialization of quantum sensors



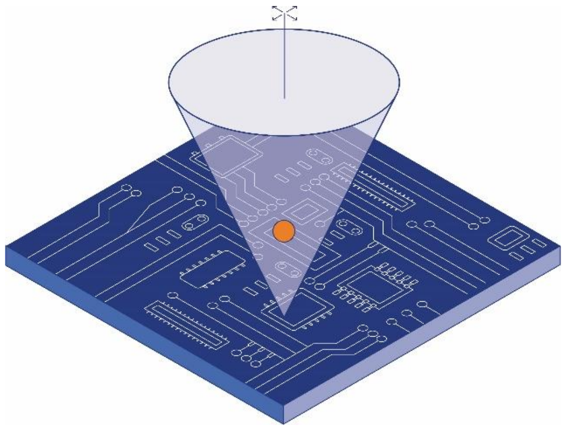
Testbed Facility





Our Instruments

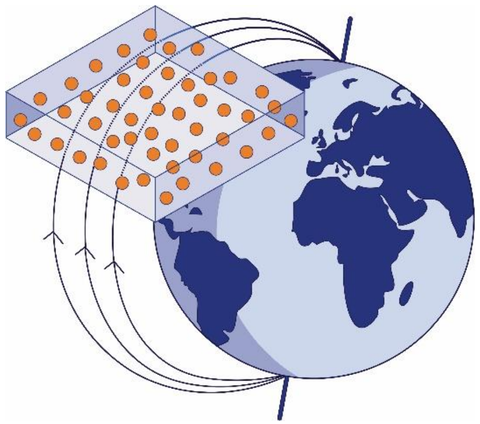
1. Scanning probe microscopes



Features

- Resolution $\sim 50 \text{ nm}$
- Sensitivity $\sim 5 \frac{\mu T}{\sqrt{Hz}}$
- Target speed: 100 pixels per second

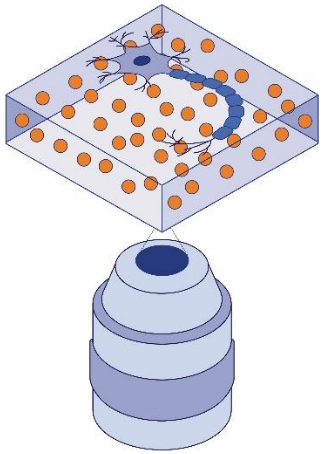
2. Compact magnetometers



Features

- Resolution $\sim 3 \text{ mm}$
- Sensitivity $\sim 1 \frac{nT}{\sqrt{Hz}}$
- Free-space, PICs and Fiber based solutions

3. Wide field microscopes



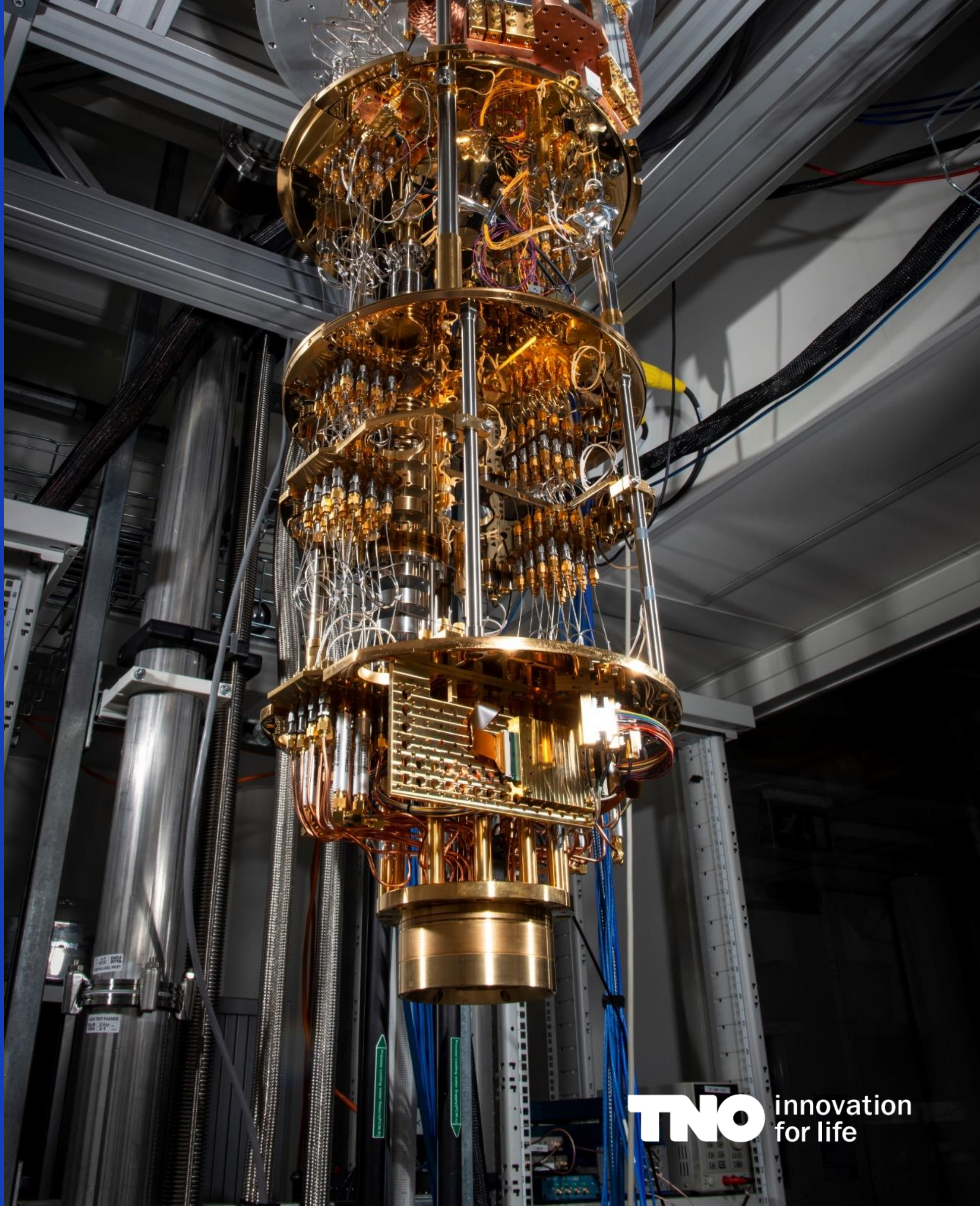
Features

- Resolution ~400 nm
- Sensitivity ~500 $\frac{nT}{\sqrt{Hz}}$

How to join the revolution of Quantum? By investing!

About the investment landscape & needs within the field

Gert-Jan Vaessen | Deep Tech Fund Manager, Invest-NL



Quantum funding in NL

- Investment in Quantum Technology has been steadily increasing in multiple advanced economies.
- The Netherlands is employing its own dedicated national €613 million program, managed by QuantumDelta Netherlands.
- The Netherlands currently ranks 2nd in terms of per capita public spending among the 12 largest public investors. However, when it comes to total spending, the Netherlands ranks 10th, with China surpassing all others by a significant margin .
- Currently, the most significant developments in commercial Quantum technologies and applications are driven by private companies, often working closely with academic institutions.

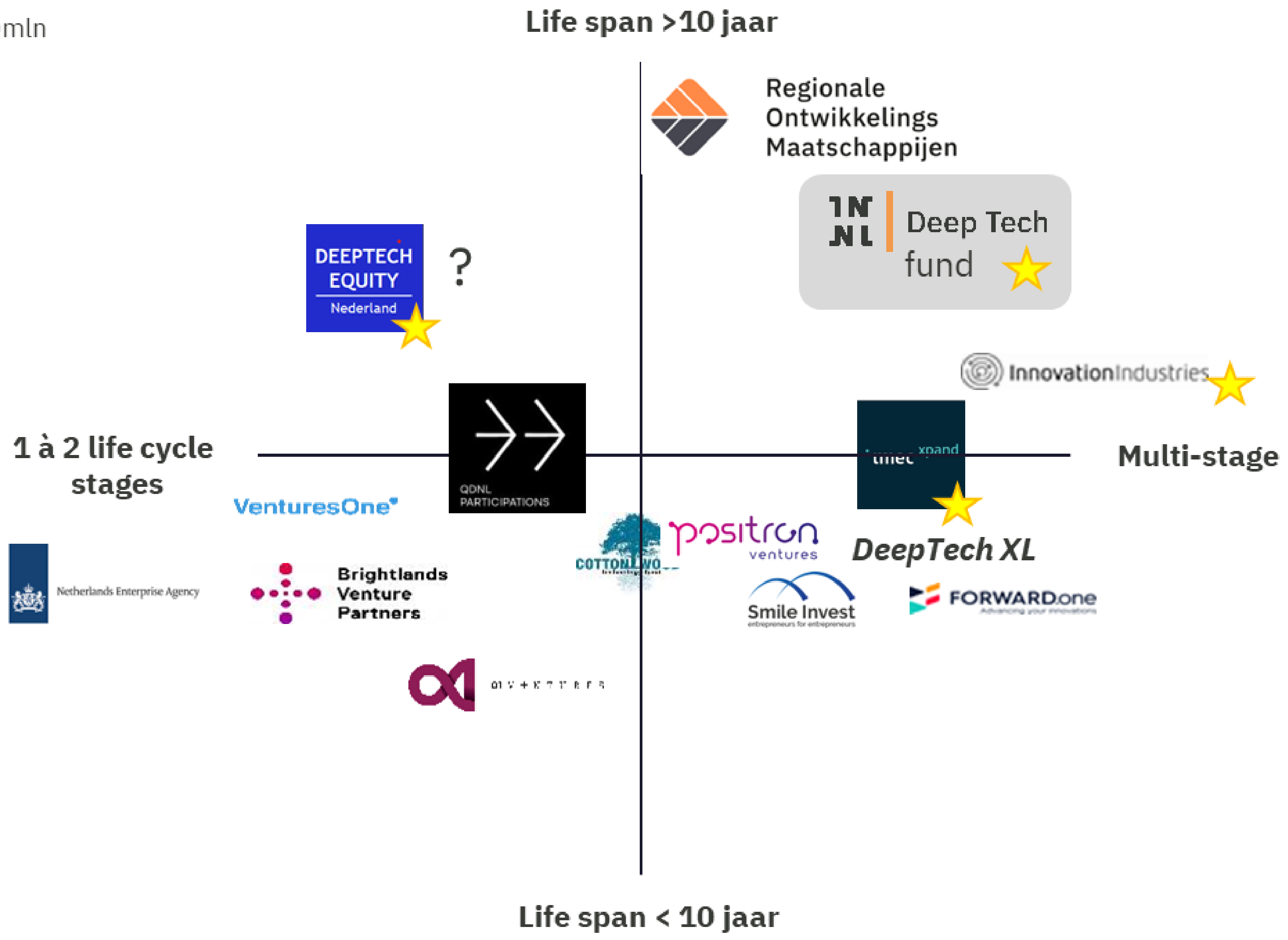
Country	Funding per capita [$/p]	Ranking #
Germany	77	1
Netherlands	51	2
Israel	48	3
Canada	42	4
UK	37	5
France	34	6
China	18	7
EU	16	8
Japan	14	9
US	11	10
Russia	6	11
India	1	12

The Netherlands Is Putting A Call Out For Quantum Investors

Daily, National Matt Swayne • October 31, 2023

(Deep)tech fund landscape in NL

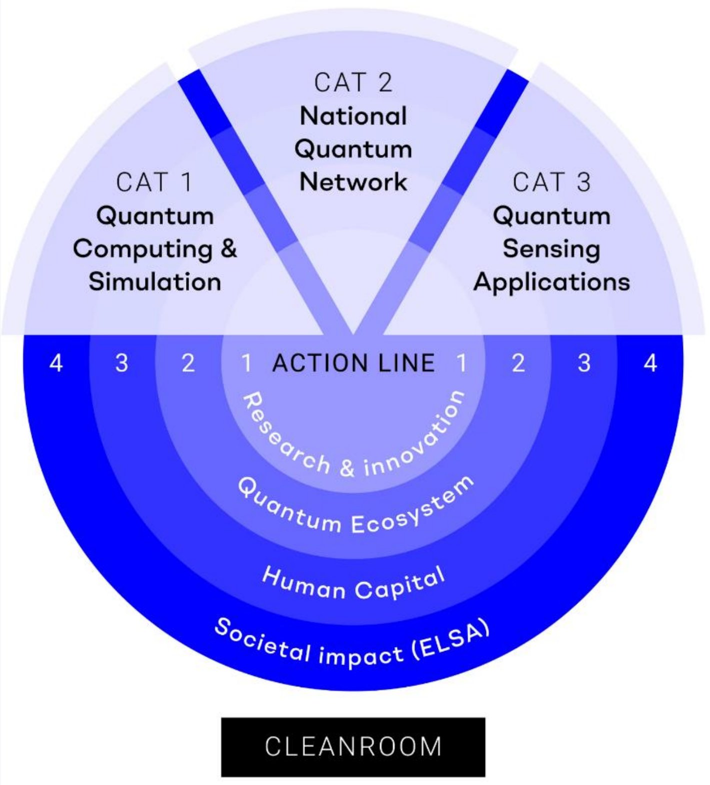
★ Fundsize > €200mln



Good News: Public Private Collaborations supported by Growth Fund QDNL – goals & how to collaborate

Catalyst programs focus on accelerate introduction of Quantum to the market and the real world lowering barriers to development and testing.
Action lines define domains of focus and align participants and resources toward a common theme.

Cleanroom facilities at our five hubs across the Netherlands. QDNL provides the essential cleanroom facilities.



How to collaborate & accelerate

Quantum Technology at TNO

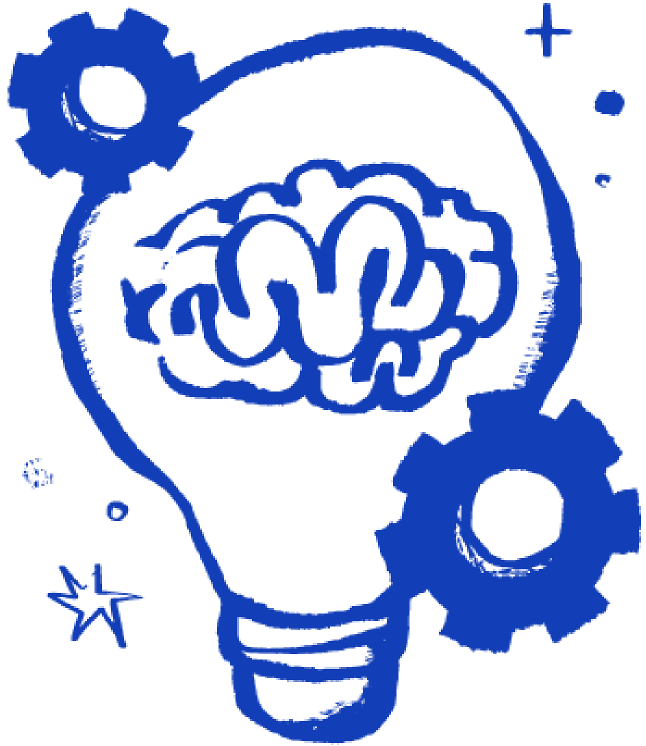
- We develop the devices and systems that will enable the second Quantum revolution

People	Technologies	Facilities
Nanofabrication engineers System engineers Quantum Scientists Project managers	Quantum devices development Quantum computing Quantum communication Quantum sensing	State-of-the-art cleanroom facilities Quantum system integration labs

> 150 FTE in the mentioned application areas

How to collaborate (contact via tno.nl/fasttrack)

- **TNO Fast Track**
  - Facilities
  - Network
  - 3500 Experts
- **Invest-NL**
  - Funding
- **QDNL / Infinity**
  - Network



QUANTUM QUICKSCAN

- **This is what you have:**
  You are an SME for which Quantum could be interesting – as an end-user, producer etc.
- **This is what you get:**
  - Overview of the Quantum market
  - Insight into which Quantum technologies are relevant to your company
  - View of possible Quantum applications within your company

Go to: https://fasttrack.tno.nl/activiteiten/quantum-quickscan/

WRAP-UP & Q&A

- Basic principles of Quantum Technology
- State of Tech, in particular Quantum Sensing: A lot is already possible
- More private investment needed to stay ahead!
- How to collaborate and accelerate: TNO, QDNL, Invest-NL
- Are there any questions?

Thanks for your attention!